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NASA TM X- 70 487

CONTROL OF CONTAMINANTS ON SENSORS

REPORT #1: INTERDIRECTORATE WORKING GROUP ON EARTH OBSERVATION SENSORS

W. HOVIS
D. SMITH
A. McCULLOCH
I. L. GOLDBERG
H. OSTROW
B. SEIDENBERG

OCTOBER 1973

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

(NASA-TM-X-70487) CONTROL OF CONTAMINANTS ON SENSORS. REPORT 1: INTERDIRECTORATE WORKING GROUP ON EARTH OBSERVATION SENSORS (NASA) 10 p HC $3.00 CSCL 14B

N73-33367

Unclas
G3/14 19343

X-652-73-306

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W. Hovis, Chairman
D. Smith
A. McCulloch
I. L. Goldberg
H. Ostrow
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I. INTRODUCTION

Recent experience with sensors in orbit has indicated that contamination is becoming a more serious problem as more sophisticated sensors are launched. The Nimbus HRIR cooler at 195°K exhibited a slow warming that could have been caused by contamination on the cooler surfaces. The Nimbus 4 Filter Wedge Spectrometer showed strong evidence of contamination by water ice on the optics, probably on the detector itself. The ERTS-1 Multi-Spectral Scanner sun calibration system was virtually useless when activated, apparently due to contaminants on the solar pickoff mirrors that had reduced mirror reflectance upon exposure to solar irradiation. The Nimbus 5 SCMR solar calibration was also found to be degraded when it was first examined.

The ERTS-1 MSS experience caused a rather detailed look into the problem of contamination during spacecraft level vacuum thermal testing. Tests conducted during and after the thermal vacuum period showed that a large number of contaminants were being deposited on the spacecraft, including the sensors, during the thermal vacuum cycle. Contaminants identified included phthalate esters, sulfonamides, methy phenyl silicone and polyol. Details of quantities found and their probable source can be found in the Nimbus E Launch Readiness Review report, dated 26 and 27 October, under the section entitled "Materials Performance."

Contaminants found on Nimbus E were not only detected chemically and spectroscopically but were, in some cases, quite easily visible to the eye on optical surfaces such as scan mirrors. The scan mirrors that exhibited contamination were cleaned after thermal vacuum but it was impossible to clean all other surfaces of the spacecraft and sensors so a considerable contaminant load was carried into orbit with the spacecraft. Outgassing from such contaminants as well as other outgassing from spacecraft and sensor components presents a major problem to sophisticated sensors. Obviously, it is not the function of the individual experimenter to clean up the spacecraft or the vacuum thermal test chamber but the experimenter can, to some degree, protect his sensor from contamination and design his sensor for ease of cleaning should contamination occur. This document will deal with recommendations to that effect as made by members of the Interdirectorate Working Group on Earth Observation Sensors.

The recommendations made here are not represented as all inclusive and are not intended as a substitute for common sense. They are, rather, a result of lessons learned the hard way and a first attempt at documenting those lessons to avoid unnecessary repetition of problems.

II. DESIGN PRECAUTIONS

A. Access to Optical Surfaces

All optical surfaces exposed to the atmosphere, either ambient or in thermal vacuum are subject to contamination during testing. Such surfaces should be accessible for cleaning without the necessity for removal or realignment of the optical train. Primary and secondary mirrors of Cassegrain telescopes have been particularly hard to clean since they are usually recessed into cast housings. Access plates should be included, whenever possible, to facilitate cleaning of such surfaces.

B. Venting of Outgassing Products

Many components of a sensor such as lubricants, electronic components and plastics will outgas for a portion or, in some cases, the entire life of a sensor. If at all possible, optical components should be isolated from such sources of contaminants. In particular, a venting path for such outgassed vapors should be supplied that keeps such vapors as far as possible from the optical components. In no case should the venting path be through or by the optical elements such as through a Cassegrain telescope.

Care should also be taken to ensure that the vent path does not direct outgassed products into the optics of an adjacent sensor on the same spacecraft.

C. Sensors for Geosynchronous Spacecraft

Earth looking sensors on geosynchronous spacecraft will receive direct solar irradiance into the main sensor optics unless the optics are protected. When viewing the dark side of Earth, especially at sunset and sunrise at the limb, it is extremely difficult to prevent sunlight from entering the main optical cavity of a sensor. When the earth is in daylight the optical cavity of most sensors will radiate more energy than received from earth since the earth will fill only 0.09 steradians. A shield that will restrict the sensor field of view to about 0.09 steradians will lessen the radiative energy loss and moderate the tendency of the sensor to cool off when viewing the sunlit earth.

When the sun passes behind earth and the sensor is viewing the night side, solar energy can enter the optics. Even if the sun never falls on the optical axis of the sensor, sunlight can cause damage to optical components by heating and by irradiating contaminants causing effects such as have been seen on sun calibration optics. If at all possible, the sensor optics should be covered to prevent sunlight from reaching them. If nighttime sensing is essential, a sun shield must be included in the sensor to restrict the field of view to as small an angle as possible.

III. ON BOARD CALIBRATION

The sun is an attractive source for on board calibration of sensors operating in the ultraviolet, visible and infrared but serious problems have developed on sensors using a solar calibration. Specular reflectors used to direct the solar input into several scanners have apparently degraded rapidly after exposure to solar irradiance. The mirrors involved were used only for calibration in the visible and near infrared but were exposed to the full spectrum of solar energy.

Heath and Haney (GSFC X-651-72-478) conclude, after analysis of data from the Nimbus MUSE and BUV experiments, that the most likely source of degradation observed in the MUSE and BUV is micrometer size particles outgassed by the spacecraft and fixed on optical surfaces by uv solar radiation. Their observations would be consistent with the degradations observed on the ERTS MSS and Nimbus HRSCMR since a loss of specular reflectance would result in an overall signal loss. Diffusely scattered energy would not be detected in either instrument.

Until the exact cause of specular reflector degradation is determined and a method to avoid degradation devised, it is adviseable to use only diffuse surfaces exposed directly to the sun for calibration or not rely on solar calibration. Surfaces that view the sun directly are normally not utilized during thermal vacuum testing and should be covered when not in use to minimize contamination buildup. If diffuse surfaces cannot be used and a specular element is required the specular element should have replaceable facets and be covered except when absolutely necessary.

IV. SENSOR CONSTRUCTION

The materials used in sensor construction should obviously be those that outgas as little as possible and should be handled to insure that as much outgassing as possible occurs before the optics are exposed to such outgassing.

A. Paints

Paints have been found to be a troublesome source of outgassing. Whenever paints are necessary they should be applied and treated before attachment of parts, whose characteristics would restrict treatment. The commonly used black paint, 3M 401-C10, should be air dried for 48 hours then vacuum baked at 107°C in a vacuum of 10^{-6} torr or better for 72 hours. If the paint is damaged during subsequent tests, when treatment of the painted section by heating in a vacuum is no longer possible, touch up painting should be avoided unless absolutely necessary. If necessary the retouched area should be heated with a heat gun while all other sensor surfaces are protected from the products that will outgas. For white surfaces an inorganic paint is recommended either I.I.T.R.I. type Z-93 or MS74 from G.S.F.C. Information on the proper application of these paints can be gotten from Julius Hirschfield, Code 765, G.S.F.C. These paints can be cured by air drying.

B. Plastics

Plastic components appear to be inevitable in spacecraft sensors, especially in the electronics section. Guidance in selection of plastics can be gotten from "A Compilation of Low Outgassing Polymeric Materials Normally Recommended for GSFC Cognizant Spacecraft", GSFC X-764-71-314 by A. Fisher and B. Mermelstein.

Each application must be considered individually and the selection of materials made on the basis of function of the plastic and its outgassing characteristics. Plastics should be isolated, to the extent possible, and care taken that the venting path avoids the optical elements.

Even if a particular plastic is known to outgas little, care should be taken that residues from the manufacturing process are not present that could cause contamination. If there is any doubt plastics should be cleaned with isopropyl alcohol before use in a sensor.

Plastic adhesives are frequently used, even to cement optics into place. They present a particular problem in that those that outgas least are quite hard after setting. Dow Corning C6-1104 is good from an outgassing standpoint, but quite hard after setting. RTV 566 outgasses more but is softer providing a better cushion for mounting than C6-1104.

C. Lubricants

Lubricants are normally selected that have low vapor pressures. Even so some outgassing occurs so, as with all other outgassed products, lubricated parts should be isolated from optical components and vent paths provided away from such components.

Proper oil barriers are required to prevent oil from creeping out of the bearing cavity with close fitting bearing shields to reduce the gas flow and prevent contamination from either entering or leaving the bearing housing. The weight loss rate of the selected lubricant will depend upon the operating temperature of the bearing including the instantaneous point contact heating within the bearing. Since this local contact surface heating is very difficult to estimate, a lubricant should be selected with as high an operating temperature as possible, that is, considerably higher than the bearing housing temperature may dictate and still maintain a minimum outgassing rate. Examples of the best lubricating oils presently available which fall in this category and have less than 1/2 mg/hr. weight loss rate at 60 °C in a vacuum, are Krytox 143 AB and Apiezon D. An example of grease which meets the same weight loss criteria at 40°C is 240 AB. Dry film lubricants such as MOS_2 can also be used but may not support the bearing under high loads or high speeds. With the high outgassing rates which can occur, labyrinth bearing shields are preferred with care taken that the venting path avoids the optical and cooler elements.

D. Radiative Coolers

Radiative Coolers are one of the most sensitive areas to contaminants since the patch-detector assembly is usually the coldest thing on the spacecraft. Some contaminants may be unavoidable but can be minimized by taking extreme care with materials used in the cooler and sensor design.

No venting should be possible through the cooler from the rest of the sensor. The cooler area should be sealed off by a window, preferably not cooled but if cooled capable of being warmed to a temperature higher than the rest of the sensor it faces. The materials in the cooler, especially paints, should be treated as mentioned in Section IV A.

All elements of the cooler assembly should be capable of being heated both during normal operation and during launch. If sufficient electrical power is not available to provide such heating a deployable cover should be utilized to keep the cooler warm, in conjunction with the electrical heaters.

The cooler should be constructed so that it can be maintained at a temperature above most of the other elements of the spacecraft for at least two weeks after launch. Recent experience has shown that coolers allowed to cool down as soon as possible after launch degrade, probably by contaminant buildup, and the degradation is not reversible by subsequent heating.

V. STORAGE AND TRANSPORTATION

Sensors are frequently stored for long periods, usually in specially designed containers, awaiting integration onto the spacecraft. Sensor containers should be purchased or constructed with contamination avoidance in mind. It is of little use to carefully construct a sensor, with great care in materials selection, and then store it for long periods in a container that will expose it to a steady dose of contamination.

If plastics and glues are necessary for container construction, they should be selected for low outgassing properties. Plastics such as vinyls should never be utilized in shipping containers. Purging of instruments during storage or even on spacecraft should be carried out with extreme care. Purge gases should be contaminant free and transfer lines should be cleaned before use. Tubing with a high outgassing rate, such as Tygon tubing, should never be used to purge a sensor.

Plastic covers are frequently used to protect optics. Hard materials such as Lucite are useful but should be cleaned with isopropyl alcohol before use. Clinging plastic films have also been used as covers and here special care is needed. Films such as Saran Wrap and those containing poly vinyl chloride or cellulose acetate outgas harmful contaminants and should never be used. Only mylar or polyethlene should be used as thin films and they should be washed in isopropyl alcohol before use to remove any manufacturing residue.

VI. THERMAL VACUUM TESTING

Thermal Vacuum Testing has proven to be one of the most dangerous times for sensors, from a contamination standpoint. A number of sensors have been contaminated with diffusion pump oil from back streaming. This can only be prevented by good vacuum technique including provision for containing the sensor in the event of power failure to the pumps.

Recently, a number of cases have occured where an oily appearing residue was found, after thermal vacuum, on parts in chambers that were cold during testing. The oily appearance led to an erroneous conclusion that the substance was diffusion pump oil. Chemical tests have shown, in several cases, that the residue was outgassed phthalates from vinyls in the chamber. Tygon tubing and vinyl insulated wire have been identified as sources of such contamination. Special care should be taken to make sure that such materials are not allowed in vacuum systems.

In some thermal vacuum test, components within the vacuum chamber may be heated to control thermal balance, test heaters or by lamps utilized for a number of purposes. Surfaces to be heated should not be coated with any material prone to outgassing. If this is not possible care should be taken to see that optical elements have no direct view of heated surfaces. Optical components should be screened from any heated surfaces to prevent line of sight deposition of contaminants. Optical elements that are not utilized in thermal vacuum tests should be covered to minimize contamination.

VII. CLEANING CONTAMINATED OPTICS

The best general cleaning agent from the standpoint of removing contaminants and not adversely affecting surrounding parts, is isopropyl alcohol. Some special optical elements may not be able to be cleaned with alcohol but the vast majority of mirrors, lenses, filters and other optical components are not harmed by isopropyl alcohol. Components and materials in proximity to optical elements should be selected so that they are not harmed by alcohol.